United States
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**Soil
Conservation
Service**

Agricultural
Waste Management
Field Handbook

# Chapter 6 Role of Plants in Waste Management

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Contents:

## Tables



## Figures

# Chapter 6 Role of Plants in Waste Management

## 651.0600 Introduction

Many agricultural operations produce waste by-products. Animal manure is an example of a waste by-product that can be used as a plant nutrient. Properly managed and utilized agricultural wastes are a natural resource that can produce economic returns. Waste management systems properly planned, designed, installed, and maintained prevent or minimize degradation of soil, water, and air resources while providing chemical elements essential for plant growth.

The objectives of a complete system approach to waste management are to design a system that

- recycles nutrients in quantities that benefit plants,
- builds levels of soil organic matter,
- limits nutrient or harmful contaminant movement to surface and ground water,
- does not contaminate food crops with pathogens or toxic concentrations of metals or organics, and
- provides a method in the soil environment to fix or transform nonessential elements and compounds into harmless forms.

This chapter will provide the reader with an appreciation for the plant's role in management of nutrients in an agricultural waste management system. The function and availability of plant nutrients as they occur in agricultural wastes are discussed, and the effects of trace elements and metals on plants are introduced. General guidance is given so the components of the waste can be converted to plant available form and the nutrients harvested in the crop can be estimated. The impact of excess nutrients, dissolved solids, and trace elements on plants is given in relationship to agricultural waste application.

## 651.0601 Agricultural waste as a resource for plant growth

The primary objective of applying agricultural waste to land is to recycle part of the plant nutrients contained in the waste material into harvestable plant forage, fruit, or dry matter. An important consideration is the relationship between the plant's nutrient requirement and the quantity of nutrients applied in the agricultural wastes. A plant does not use all the nutrients available to it in the root zone. The fraction of the total that is assimilated by the roots varies depending on the species of plant, growth stage, depth and distribution of its roots, moisture conditions, soil temperature, and many other factors. The uptake efficiency of plants generally is not high, often less than 50 percent. Perennial grasses tend to be more efficient in nutrient uptake than row crops. They grow during most of the year, and actively grow during the period of waste application, which maximizes the nutrient removal from the applied waste product.

Another major objective in returning wastes to the land is enhancing the receiving soil's organic matter content. As soils are cultivated, the organic matter in the soil decreases. Throughout several years of continuous cultivation in which crop residue returns are low, the organic matter content of most soils decreases dramatically until a new equilibrium is reached. This greatly decreases the soil's ability to hold the key plant nutrients of nitrogen, phosphorus, and sulfur. These nutrients may move out of the root zone, and crop growth will suffer. The amount of crop residue that is produced and returned to the soil is reduced.

# 651.0602 The plant–soil system

The plant-soil system has advantages in using the nutrients in waste products from agricultural systems. For centuries wastes have been spread on the soil to recycle nutrients because of the positive effect on plant growth. Soils have the ability to retain plant nutrients contained in the waste. Soil retention is an important storage mechanism, and the soil is enhanced by the organic matter supplied by waste. Plants absorb the nutrients in the waste, for the most part through the roots, and transform the soluble chemical elements, some of which are water contaminants, into plant tissue. This is the basis for addressing some of today's water quality concerns. Cropping systems and precisely calculated nutrient budgets can be tailored to meet planned waste application levels and crop nutrient needs and to reduce or eliminate losses from the plant-soil system.

## (a) Nutrient transformation

Plant uptake is not the only form of nutrient transformation that takes place in the soil-plant system. The chemical compounds derived from waste material can be transformed by the following processes:

1. Absorbed by the roots and assimilated by the plant
2. Degraded by soil micro-organisms and become a part of the soil organic component, or broken down further into a gas, ion, or water
3. Fixed to soil minerals or attached to soil exchange sites
4. Solubilized and moved with runoff water.
5. Moved with eroded mineral or organic material
6. Leached downward through the soil toward the ground water
7. Escaped from plant tissue into the atmosphere

Plants can play a role in all of these processes. Processes 4, 5, 6, and 7 are nutrient escape mechanisms. Plant species and cultivars can be selected to interrupt many of these mechanisms. An example of process 4 is that cultivated crops that are conservation tilled and planted on the contour with grass sod improve removal of soluble nutrients by soil infiltration.

Other mechanisms might be active in the removal of some solid constituents. Many soil conservation actions reduce erosion, which interrupts process 5. Deep, fibrous-rooted plants or plants that can actively take up nutrients beyond the normal growing season of most agricultural crops interrupt process 6 by preventing escape of leaching soluble nutrients.

Plants can also be selected for their propensity to uptake a certain nutrient. Several crops are heavy users of nitrogen and accumulate nitrate, which is very soluble and leachable. Recent studies have shown that grass species vary significantly in their ability to remove and transform nitrogen within the soil. Alfalfa removes potassium and nitrogen in larger quantities and at a deeper rooting depth than most agricultural crops.

In other cases, plants may act as a catalyst or provide a better environment to promote the transformation processes. Plant growth moderates soil temperature, reduces evaporation from soil surface, provides an energy source of carbohydrates, and aggregates soil particles, which promotes high soil aeration. All this provides a better climate for a wide variety of soil micro-organisms, which aids process 2.

Process 3 is aided by plant growth as well, but generally this comes very slowly. The classic example is the difference in the cation-exchange capacity between a prairie soil and a forest soil derived from the same parent material. The surface layer of the prairie soil has a much higher organic matter content and cation-exchange capacity, at least double to sometimes nearly quadruple that of the forest soil (Jenny 1941). Yet, what takes centuries to build up can be quickly destroyed in less than two decades by erosion and excessive tillage (fig. 6–1). High residue crops in crop rotations help to prevent large decreases in soil organic matter content and have beneficial effects on nutrient retention (Wild 1988).

Denitrification is a classic example of nutrient transformation where microbial degradation and eventual escape of nitrogen gas occurs. It is an important process by which nitrogen in excess of crop requirement can be removed from the soil-plant system. This process requires the presence of nitrate-nitrogen, an organic carbon source, and anaerobic soil conditions. About one unit of organic carbon is required for each unit of nitrate-nitrogen to be denitrified (Firestone 1982).

Denitrification in land treatment systems is best accomplished if the nitrogen is in the nitrate form and the waste contains sufficient organic carbon to supply energy to the denitrifying micro-organism. Where the nitrogen in the waste material is in the organic or ammonium form, an aerobic condition must be present to convert the nitrogen to the nitrate form. During the aerobic process, the organic carbon will be oxidized by aerobic bacteria in the soil, leaving less carbon available for anaerobic microbial use when the system goes anaerobic.

Plant residue and roots are major sources of organic carbon for these microbial processes. The presence of living plants stimulates denitrification. This is attributed to two effects. First, low oxygen levels in the soil area immediately surrounding respiring plant roots creates the condition in which denitrifying anaerobes can exist. Second, root excretions can serve as a food source of decomposable organic carbon for the denitrifying bacteria.

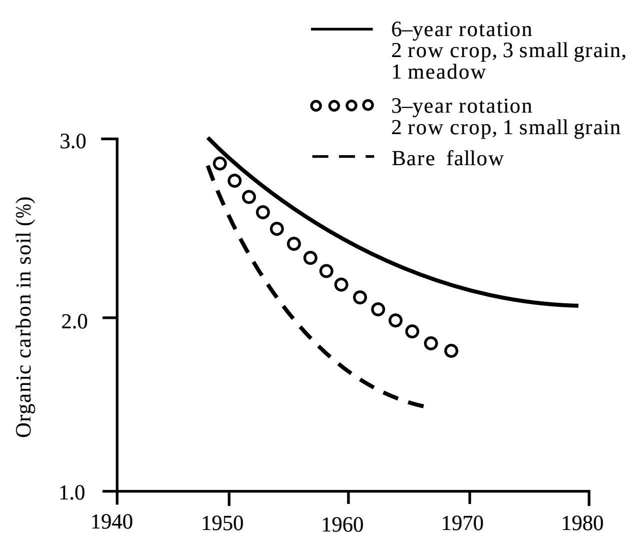
## (b) Soil supports plant growth

Plant growth involves the interaction between soil and plant properties. Soil is the normal medium for terrestrial plant root growth. A plant's roots absorb nutrients and water from the soil. Roots anchored in the soil hold the plant erect. The soil must provide the environment in which roots can function.

Optimum plant growth depends on the soil having the biological, chemical, and physical conditions necessary for the plant root system to readily absorb nutrients and water. For instance, plants require soil pore space for root extension. Plant root metabolism also depends upon sufficient pore space to diffuse gases, such as oxygen and carbon dioxide. This allows for efficient root respiration, which keeps the root in a healthy condition for nutrient uptake. A decrease in soil pore space, such as that experienced with soil compaction, retards the diffusion of gases through the soil matrix, which greatly affects root growth.

Such inhibitory factors as toxic elements (aluminum or high concentrations of soluble salts) can limit or stop plant growth. Therefore, the plant's rate of absorption of nutrients involves many processes going on in the soil and plant roots.

**Figure 6–1** The effects of different farming systems after three decades on the carbon content of soils from broken out sod ground



## 651.0603 Plant nutrient uptake

The process of element uptake by plants is complex and not totally understood. Some generally known points are:

- The process is not the same for all plants nor for all elements
- The complete process occurs within a healthy root system adequately supplied with carbohydrates and oxygen
- The essential elements must be in an available form in the root zone in balanced amounts
- Uptake varies from element to element and from crop to crop (see table 6–6)
- Soil conditions, such as temperature, moisture supply, soil reaction, soil air composition, and soil structure, affect the rate at which elements are taken up

### (a) Essential plant nutrients

Plant growth can require up to 20 chemical elements. Plants get carbon, hydrogen, and oxygen from carbon dioxide and water. Nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium are needed in relative large quantities. These elements are called macronutrients. Boron, chlorine, cobalt, copper, iron, manganese, molybdenum, silicon, sodium, vanadium, and zinc are needed in small amounts, or not at all, depending on the plant (Tisdale et al. 1985). These elements are called micronutrients or trace elements.

Macronutrients and micronutrients are taken from the soil-water solution. Nitrogen is partly taken from the air by nitrogen- fixing plants associated with soil bacteria. As a whole, the 20 elements listed are termed essential elements; however, cobalt, silicon, sodium, and vanadium are essential elements for the growth of only particular plant species.

### (b) Nonessential elements

Besides the 20 essential elements, other elements nonessential for plant growth must be monitored where municipal sludge is used as a soil amendment. These too are referred to as trace elements. Because these elements occur as impurities, they are often inadvertently applied to soils through additions of various soil amendments. Animal waste contains certain elements that can be considered nonessential. Nickel, arsenic, and copper have been found in poultry litter. Dairy manure has elevated levels of aluminum.

### (c) Nitrogen

Nitrogen is the element that most often limits plant growth. About 98 percent of the planet’s nitrogen is in the Earth’s primary rock. Nearly 2 percent is in the atmosphere, but it is 79 percent inert.

Even though nitrogen is abundant, it is still the nutrient most frequently limiting crop production. This is because the plant available forms of nitrogen in the soil are constantly undergoing transformation. Crops remove more nitrogen than any other nutrient from the soil. The limitation is not related to the total amount of nitrogen available, but to the form the crop can use.

Most of the nitrogen in plants is in the organic form. The nitrogen is incorporated into amino acids, the building blocks of proteins. By weight, nitrogen makes up from 1 to 4 percent of the plant’s harvested material.

Essentially all of the nitrogen absorbed from the soil by plant roots is in the inorganic form of either nitrate ($NO_3$) or ammonium ($NH_4$). Generally young plants absorb ammonium more readily than nitrate; however, as the plant ages the reverse is true. Under favorable conditions for plant growth, soil micro-organisms generally convert ammonium to nitrate, so nitrates generally are more abundant when growing conditions are most favorable. Once inside the root, ammonium and nitrate are converted to other compounds or transported to other parts of the plant.

### (d) Phosphorus

Phosphorus concentration in plant leaves ranges between 0.2 and 0.4 percent (Walsh & Beaton 1972). Phosphorus is important for plant growth because of its role in ribonucleic acid (RNA), the plant cells genetic material, and its function in energy transfer with adenosine triphosphate (ATP).

Phosphorus is available for absorption by plants from the soil as the orthophosphate ion ($H_2PO_4$ and $HPO_4$). These ions react quickly with other compounds in the soil to become much less available for plant uptake. The presence of aluminum, iron, calcium, and organic matter links phosphorus in highly insoluble compounds. The concentration of orthophosphate ion in the soil solution is very low, less than 0.05 mg/L, so an equilibrium is established between the soluble ion and the adsorbed form in the soil.

Phosphorus immobility in soils is caused by several factors: presence of hydrous oxides of aluminum and iron; soils that have a high clay content, especially ones high in kaolin; soils high in volcanic ash or allophane; low or high soil pH; and high exchangeable aluminum. Of these factors, the one most easily manipulated is soil pH. Maintaining a soil pH between 6.0 and 6.5 achieves the most plant available phosphorus in a majority of soils. Knowing the extent each of the factors are at work in a particular soil gives the upper limit at which phosphorus loading can occur in the soil before soluble phosphorus leaching from the soil becomes a serious water quality concern.

The relative immobility of phosphorus in the soil profile allows some agricultural waste to be applied in excess of the crop's nutrient needs, resulting in a soil phosphorus residual. Building a soil phosphorus residual can be beneficial in soils that readily fix phosphorus into an insoluble, unavailable form for plant uptake. This phosphorus reservoir, if allowed to rise, gives a corresponding rise in the soluble phosphorus content in the soil. This addition of total phosphorus has to be tempered with some restraint.

Manure applications can actually increase phosphorus leaching because organic phosphorus is more mobile through the soil profile than its inorganic counterparts. This would be particularly true on coarse textured soils that have a low cation-exchange capacity and low content of iron, aluminum, and calcium.

High phosphorus application rates appreciably increase the phosphorus concentration in the soil solution and availability for plant uptake into plant tissue, but this phosphorus rarely becomes toxic to the plant. Phosphorus toxicity depends on the plant species, phosphorus status of the plant, concentration of micronutrients, and soil salinity. Poor growth in plants that have high phosphorus levels can cause reduced nodulation in legumes, inhibition of the growth of root hairs, and a decrease in the shoot to root ratio (Kirkham 1985).

## (e) Potassium, calcium, and magnesium

Potassium, calcium, and magnesium have similar reactions in the soil. The similar size and uptake characteristic can cause plant fertility problems. An excess of any one of these elements in the soil impacts the uptake of the others. It is, therefore, extremely important not to create nutrient imbalances by overapplying one of these elements to the exclusion of the others. Upon mineralization from the organic material, each element produces cations that are attracted to negatively charged particles of clay and organic matter.

Potassium is much less mobile than nitrogen, but more so than phosphorus. Leaching losses of potassium generally are insignificant except in sandy and organic soils. This is because sandy soils have a low cation-exchange capacity and generally do not have a clayey subsoil that can re-adsorb the leaching potassium. Potassium can leach from organic soils because the bonding strength of the potassium cation to organic matter is weaker than that to clay (Tisdale et al. 1985).

Some potassium is leached from all soils, even in the humid regions in soils that have strong fixing clays, but the losses do not appear to have any environmental consequences. Potassium leached from the surface soil is held in the lower horizons of the soil and returned to the surface via plant root uptake and translocation to above ground plant parts. Calcium and magnesium can occur in drainage water, but this has not been reported to cause an environmental problem. In fact, it can be beneficial in some aquatic systems. Total dissolved salts content may increase.

## (f) Sulfur

Part of the sulfur applied to well drained soils ends up in sulfate form. Sulfur is oxidized by soil bacteria and fungi. The plant absorbs the oxidized sulfate ion. Sulfate concentrations between 3 and 5 mg/L in the soil are adequate for plant growth. Sulfates are moderately mobile and may be adsorbed on clay minerals, particularly the kaolinitic type, and on hydrous oxides of aluminum and to a lesser extent iron. If the soils in the waste management system are irrigated, sulfates can leach into the subsoil and even into ground water. Under poor drainage conditions, sulfates are converted mainly to hydrogen sulfide and lost to the atmosphere. In some instances, they are converted to elemental sulfur in waterlogged soils.

## (g) Trace elements

Trace elements are relatively immobile once they are incorporated into the soil. The one nonmetal, boron, is moderately mobile and moves out of the rooting depth of coarse textured, acidic soils and soils that have a low organic matter content. The levels of plant available forms of all these elements are generally very low in relation to the total quantity present in soils. Some of these elements are not available for most plants to take up.

Soil reaction has the greatest influence on availability of trace elements that are taken up by plants. Except for molybdenum, the availability of trace elements for plant uptake increases as the soil pH decreases. The opposite occurs for molybdenum. For most agricultural crops, a pH range between 6.0 and 7.0 is best. As soil acidity increases, macronutrient deficiencies and micronutrient toxicity can occur depending on the nutrient, its total quantity available in the soil, and the plant in question. In alkaline soils, crops can suffer from phosphorus and micronutrient deficiencies.

Two nonessential elements of primary concern in municipal sludge are lead and cadmium. At the levels commonly found in soils or sludges, these elements have no detrimental effect on plant growth, but, they can cause serious health problems to the people or animals eating plants that are sufficiently contaminated with them. Lead can be harmful to livestock that inadvertently ingest contaminated soil or recently applied sludge while grazing. Cadmium, on the other hand, is taken up by some plants quite readily (table 6–1). If the plants are eaten, this element accumulates in the kidneys and can cause a chronic disease called proteinuria. This disease is marked by an increase of protein content in the urine.

Another nonessential element of concern is nickel. In high enough concentrations in the soil, it can become toxic to plants. Hydroxylic acid reacts with nickel to inhibit the activity of the urease molecule. This can interfere with plant metabolism of urea.

**Table 6–1** Relative accumulation of cadmium into edible plant parts by different crops (USEPA 1983)*

| High uptake | Moderate uptake | Low uptake | Very low uptake |
|---|---|---|---|
| Lettuce | Kale | Cabbage | Snapbean family |
| Spinach | Collards | Sweet corn | Pea |
| Chard | Beet roots | Broccoli | Melon family |
| Escarole | Turnip roots | Cauliflower | Tomato |
| Endive | Radish globes | Brussels sprouts | Pepper |
| Cress | Mustard | Celery | Eggplant |
| Turnip greens | Potato | Berry fruits | Tree fruits |
| Beet greens | Onion | | |
| Carrots | | | |

* The classification is based on the response of crops grown on acidic soils that have received a cumulative cadmium (Cd) application of 4.5 lb/ac. It should not be implied that these higher uptake crops cannot be grown on soils of higher Cd concentrations. Such crops can be safely grown if the soil is maintained at pH of 6.5 or greater at the time of planting because the tendency of the crop to assimilate heavy metals is significantly reduced as the soil pH increases above 6.5.

Two essential elements, zinc and copper, can also become toxic to plant growth if soil concentrations are excessive. These elements become toxic because they are mutually competitive as well as competitive to other micronutrients at the carrier sites for plant root uptake. Excessive concentrations of either element in the available form induces a plant nutrient deficiency for the other. High soil concentrations of copper or zinc, or both, can also induce iron and manganese deficiency symptoms (Tisdale et al. 1985).

In all, five elements of major concern have been targeted by the Environmental Protection Agency when sludge is applied to agricultural land. They are cadmium, copper, nickel, lead, and zinc. Table 6–2 shows their recommended cumulative soil limits in kilograms per hectare and in pounds per acre. Note that these loading limits depend on the soil's cation-exchange capacity and a plow layer pH maintained at 6.5 or above. Application of wastes that have these elements should cease if any one of the elements' soil limit is reached (USEPA 1983). Some states have adopted more conservative limits than those shown in table 6–2. State regulations should be consulted before designing a waste utilization plan.

Other trace elements have been identified as harmful to plant growth or potentially capable of occurring in high enough concentrations in plant tissue to harm plant consumers. They are aluminum, antimony, arsenic, boron, chromium, iron, mercury, manganese, and selenium. Generally, they do not occur in wastes, such as sludges, in high enough concentrations to pose a problem or they are only minimally taken up by crops (USEPA 1983).

As seen in table 6–1 for cadmium uptake, plants differ in their capacity to absorb elements from the soil. They also differ greatly in their tolerance to trace element phytotoxic effects. Tables giving specific tolerance levels for plant uptake are needed for individual plant species. Almost any element in the soil solution is taken into the plant to some extent, whether needed or not. An ion in the soil goes from the soil particle to the soil solution, through the solution to the plant root, enters the root, and moves from the root through the plant to the location where it is used or retained.

## (h) Synthetic organic compounds

When dealing with municipal sludge, one other constraint to application rates should be addressed. Most sludge has synthetic organic compounds, such as chlorinated hydrocarbon pesticides, which can be slow to decompose and may be of concern from a human or animal health standpoint.

Polychlorinated biphenyls are in many sludges. Federal regulations require soil incorporation of any sludge that has more than 10 ppm of polychlorinated biphenyls wherever animal feed crops are grown. Polychlorinated biphenyls are not taken up by plants, but can adhere to plant surfaces and be ingested by animals and humans when the contaminated plant parts are eaten. Pesticide uptake by crops is minimal, and concentrations in wastes would be much less than that typically and intentionally applied to control pests on most cropland (USEPA 1983).

**Table 6–2** Recommended cumulative soil test limits for metals of major concern applied to agricultural cropland[1] (USEPA 1983)

| Metal | Soil cation-exchange capacity, meq/100g[2 3] | | |
|---|---|---|---|
| | <5 | 5 to 15 | >15 |
| | lb/ac (kg/ha) | | |
| Pb | 500 (560) | 1,000 (1,120) | 2,000 (2,240) |
| Zn | 250 (280) | 500 (560) | 1,000 (1,120) |
| Cu | 125 (140) | 250 (280) | 500 (560) |
| Ni | 125 (140) | 250 (280) | 500 (560) |
| Cd | 4.4 (5) | 8.9 (10) | 17.8 (20) |

1 Table 6-2 values should not be used as definitive guidelines for fruit and vegetable production.
2 Interpolation should be used to obtain values in CEC range 5-15.
3 Soil plow layer must be maintained at pH 6.5 or above at time of each sludge application.

# 651.0604 Balancing plant nutrient needs with waste application

Waste management must balance the capacity of the soils and plants to transform the chemical elements in the waste product by the amount that is applied or is residual in the system. A lack of plant nutrients in an available form for uptake can cause a deficiency in plants, and an excess of plant nutrients can cause toxicity. Both situations decrease plant growth. An excess can also find its way through the food chain and be hazardous to the consumer or the environment. Those elements that are not transformed or retained in the soil can leave the system and become a contaminant to surface and ground water.

## (a) Deficiencies of plant nutrients

The deficiency of nutrients to the plants from agricultural waste application can occur by either the shortage of supplied elements contained in the material or the interference in the uptake of essential nutrients caused by the excessive supply of another. In the first case, an analysis of the waste material is needed to determine the amount of plant nutrients being supplied, and this amount is balanced with the quantity required by the crop. Using the Nutrient Management Standard (590) with a nutrient budget worksheet will assure that all essential nutrients are being supplied to the crop. For the second case, an example in the section, "Excesses of plant nutrients, total dissolved solids, and trace elements," shows the antagonism that excessive uptake of ammonium ion from manure has on the calcium ion. High levels of copper, iron, and manganese in the waste material can cause a plant deficiency of zinc caused by blockage of Zn uptake sites on the root by the other ions.

## (b) Excesses of plant nutrients, total dissolved solids, and trace elements

The tolerance of plants to high levels of elements in plant tissue must also be accounted for in waste application to cropland. Heavy applications of waste can cause elevated levels of nitrates in plant tissue that can lead to nitrate poisoning of livestock consuming that foliage.

The ability to accumulate nitrates differs from plant to plant or even within cultivars of a species. Concentrations of nitrate nitrogen in plant dry matter less than 0.1 percent is considered safe to feed livestock. Large applications of waste material on tall fescue, orchardgrass, and sudangrass can cause nitrate buildup. Cattle grazing these plants can, thus, be poisoned. When the concentration of nitrate nitrogen in the dry harvested material exceeds 0.4 percent, the forage is toxic.

Animal manure releases ammonia gas upon drying. Urea contained in manure is unstable. As manure dries, the urea breaks down into ammonium. The release of gaseous $NH_3$ from manure can result in ammonia toxicity. Exposure of corn seeds to ammonia during the initial stages of germination can cause significant injury to the development of seedlings. High levels of $NH_3$ and $NH_4$ in the soil interferes with the uptake of the calcium ion causing plants to exhibit calcium deficiency (Hensler et al. 1970; Olsen et al. 1970). Part of the ammonium released is adsorbed on the cation exchange sites of the soil, releasing calcium, potassium, and magnesium ions into solution. High levels of these ions in the soil solution contributes to an increase in the soluble salt level as well as pH.

Proper handling of manure is necessary to prevent toxicity from occurring. Manure may contain high levels of ammonium nitrogen; up to 50 percent is in the $NH_4$ form. To prevent toxicity from occurring on young plant seedlings, the manure should be field spread and either immediately incorporated into the soil to adsorb the $NH_4$ on the cation exchange sites of the soil or allowed to air dry on the soil surface. Surface drying greatly reduces the level of ammonia by volatilization. Direct planting into the soil surface that is covered with manure, such as with no-till planting, can lead to germination problems and seedling injury unless rainfall or surface drying has lessened the amount of ammonia in the manure.

Applying manure at rates based on nitrogen requirements of the crop helps to avoid excess $NH_4$ buildup in the seed zone. A 0.25-inch rain or irrigation application generally is sufficient to dissipate the high concentrations of $NH_4$ in the seed zone.

Sidedressing of manure on corn, either by injection or surface application, has been shown to be an effective way to apply the inorganic portion ($NO_3$ and $NH_4$) of nitrogen that is quickly made available for plant growth (Klausner and Guest 1981). Injecting manure into soil conserves more of the ammonium nitrogen during periods of warm, dry weather and prevents ammonia toxicity to the growth of plants (Sutton et al. 1982).

The soluble salt content of manure and sludge is high and must be considered when these wastes are applied to cropland. The percent salt in waste may be estimated by multiplying the combined percentages of potassium, calcium, sodium, and magnesium as determined by laboratory analysis by a factor of two (USEPA 1979).

$$\%\text{ salts} = \left(\%\text{K} + \%\text{Ca} + \%\text{Na} + \%\text{Mg}\right) \times 2$$

Under conditions where only limited rainfall and irrigation are applied, salts are not adequately leached out of the root zone and can build up high enough quantities to cause plant injury. Plants that are salt sensitive or only moderately tolerant show progressive decline in growth and yields as levels of salinity increase (figs. 6–2, 6–3, 6–4).

Some plant species are tolerant to salinity yet sensitive during germination. If manure or sludge is applied to land in areas that receive moderate rainfall or irrigation water during the growing season, soluble salts in the waste will be dispersed through the profile or leached below the root zone. If manure or sludge are applied under a moisture deficit condition, salt concentrations can build up.

**Figure 6–2** Effect of soil salinity on growth of field crops

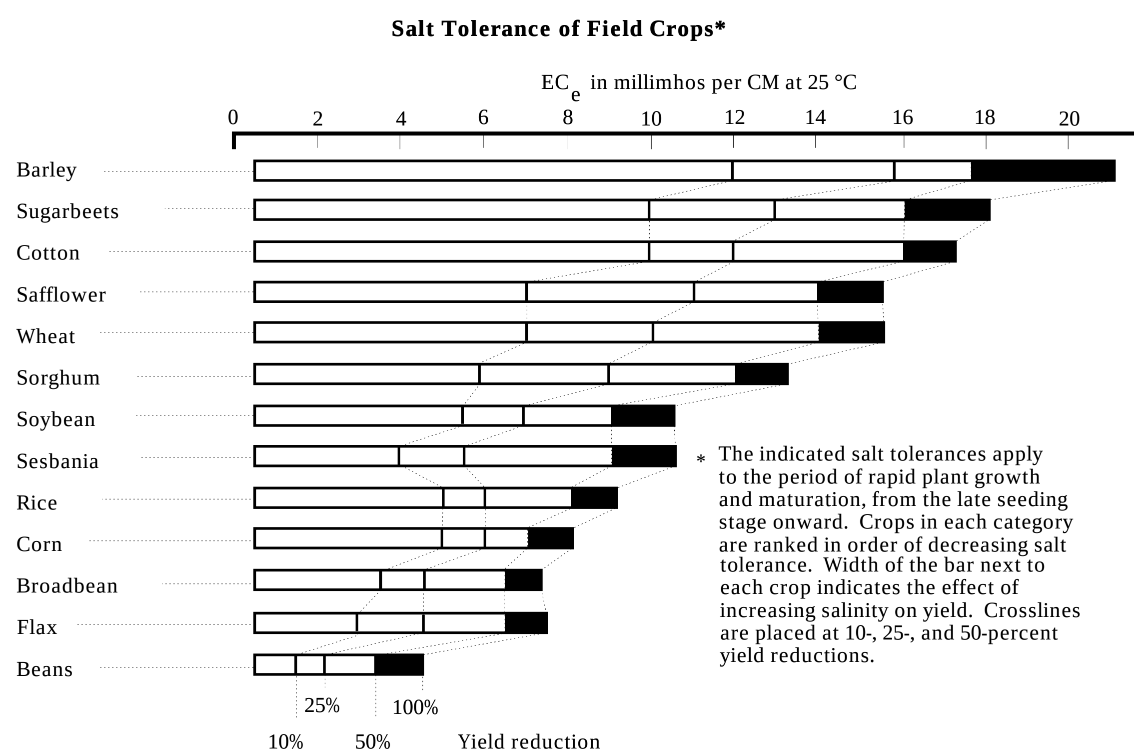
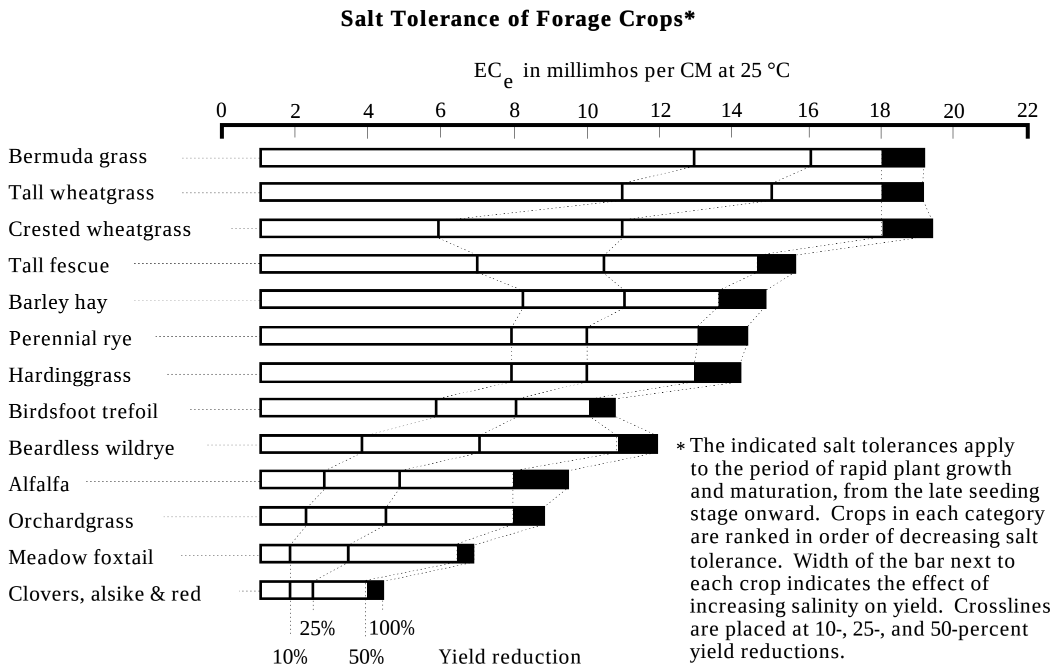
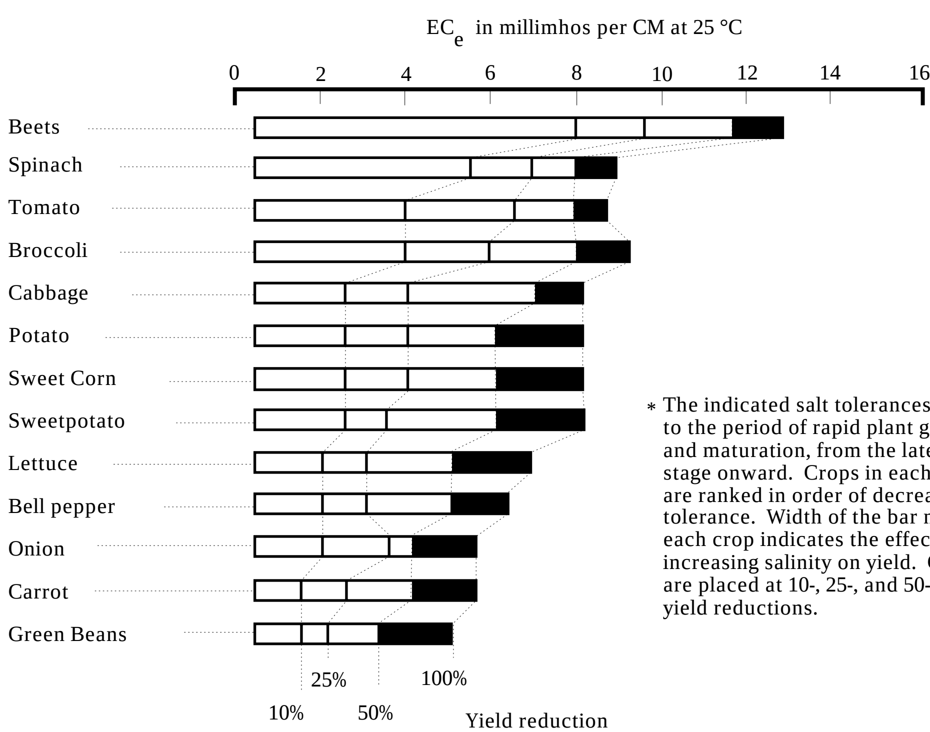


**Figure 6–3** Effect of soil salinity on growth of forage crops




* The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seeding stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10-, 25-, and 50-percent yield reductions.

**Figure 6–4** Effect of soil salinity on growth of vegetable crops




* The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seeding stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10-, 25-, and 50-percent yield reductions.

A soil test, the electrical conductivity of saturated paste extract, is used to measure the total salt concentration in the soil. After prolonged application of manure, the soil electrical conductivity should be tested. Conductivity values of 2 mmhos/cm or less are considered low in salts and suitable for all crops. Above values of 4 mmhos/cm, plant growth is affected except for all but the most tolerant crops (figs. 6–2, 6–3, 6–4). At these high conductivity values, irrigation amounts need to be increased to leach salts. Added water percolating through the profile may then cause concern with leaching of nitrates. Manure application rates may have to be adjusted (Stewart 1974).

Trace element toxicity is of concern with waste application on agricultural land. Animal manure can have elevated amounts of aluminum, copper, and zinc. Sewage sludge can have elevated concentrations of several elements, most notably aluminum, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc. The element and concentration in the sludge depends on the predominant industry in the service area. If wastes that have elevated levels of trace elements are applied over a long period of time at significant rates, trace element toxicity can occur on plants. Micronutrient and trace element toxicity to animals and humans can also occur where cadmium, copper, molybdenum, and selenium levels in plant tissue become elevated.

Table 6–3 lists some general crop growth symptoms and crops most sensitive to the given trace elements. If such symptoms should occur, a plant tissue test should be done to confirm which element is at fault. Many of the symptomatic signs are similar for two or more elements, making it extremely difficult to know with certainty which element is in excess from observation of outward symptoms. Much of the toxicity of such trace elements can be because of their antagonistic action against nutrient uptake and use by plants. Table 6–4 shows the interaction among elements within plants and adjacent to the plant roots.

# 651.0605 Application of agricultural waste

## (a) Field and forage crops

Manure and sewage have been used for centuries as fertilizers and soil amendments to produce food for human and animal consumption. Generally, manure and sludges are applied to crops that are most responsive to nitrogen inputs. Field crops that are responsive include corn, sorghum, cotton, tobacco, sugar beets, and cane.

Sewage sludge should not be used on tobacco. The liming effect of the sludge can enhance the incidence of root diseases of tobacco. It can also elevate cadmium levels in tobacco leaves, rendering it unfit for marketing (USDA 1986).

Cereal grains generally do not receive fertilizer application through manure because spreading to deliver low rates of nitrogen is difficult. Small grains are prone to lodging (tipping over en masse under wet, windy conditions) because of the soft, weak cell walls derived from rapid tissue growth.

Legumes, such as alfalfa, peanuts, soybeans, and clover, benefit less by manure and sludge additions because they fix their own nitrogen. The legumes, however, use the nitrogen in waste products and produce less symbiotically fixed nitrogen. Alfalfa, a heavy user of nitrogen, can cycle large amounts of soil nitrogen from a depth of up to 6 feet. Over 500 pounds per acre of nitrogen uptake by alfalfa has been reported (Schuman & Elliott 1978; Schertz & Miller 1972).

The great danger of using manure and sludges on legume forages is that the added nitrogen may promote the growth of the less desirable grasses that are in the stand. This is caused primarily by introducing another source of nitrogen, but it can also be a result of the physical smothering of legume plants by heavy application cover of manure.

Grass tetany, a serious and often fatal disorder in lactating ruminants, is caused by a low magnesium content in rapidly growing cool season grasses. Cattle grazing on magnesium deficient forage develop health problems. High concentrations of nitrogen and potassium in manure applications to the forages aggravate the situation. Because of the high levels of available nitrogen and potassium in manure, early season applications on mixed grass-legume forages should be avoided until the later-growing legume is flourishing because legumes contain higher concentrations of magnesium than grasses.

**Table 6–3** General effects of trace element toxicity on common crops (Kabata & Pendias 1984)

| Element | Symptoms | Sensitive crop |
|---|---|---|
| Al | Overall stunting, dark green leaves, purpling of stems, death of leaf tips, and coralloid and damaged root system. | Cereals. |
| As | Red-brown necrotic spots on old leaves, yellowing and browning of roots, depressed tillering. | (No information.) |
| B | Margin or leaf tip chlorosis, browning of leaf points, decaying growing points, and wilting and dying-off of older leaves. | Cereals, potatoes, tomatoes, cucumbers, sunflowers, mustard. |
| Cd | Brown margin of leaves, chlorosis, reddish veins and petioles, curled leaves, and brown stunted roots. | Legumes (bean, soybean), spinach radish, carrots, and oats. |
| Co | Interveinal chlorosis in new leaves followed by induced Fe chlorosis and white leaf margins and tips, and damaged root tips. | (No information.) |
| Cr | Chlorosis of new leaves, injured root growth. | (No information.) |
| Cu | Dark green leaves followed by induced Fe chlorosis, thick, short, or barbed-wire roots, depressed tillering. | Cereals and legumes, spinach, citrus, seedlings, and gladiolus. |
| F | Margin and leaf tip necrosis; chlorotic and red-brown points of leaves. | Gladiolus, grapes, fruit trees, and pine trees. |
| Fe | Dark green foliage, stunted growth of tops and roots, dark brown to purple leaves of some plants ("bronzing" disease of rice). | Rice and tobacco. |
| Hg | Severe stunting of seedlings and roots, leaf chlorosis and browning of leaf points. | Sugarbeets, corn, and roses. |
| Mn | Chlorosis and necrotic lesions on old leaves, blackish-brown or red necrotic spots, accumulation of $MnO_2$ particles in epidermal cells, drying tips of leaves, and stunted roots. | Cereals, legumes, potatoes, and cabbage. |
| Mo | Yellowing or browning of leaves, depressed root growth, depressed tillering. | Cereals. |
| Ni | Interveinal chlorosis in new leaves, gray-green leaves, and brown and stunted roots. | Cereals. |
| Pb | Dark green leaves, wilting of older leaves, stunted foliage, and brown short roots. | (No information.) |
| Rb | Dark green leaves, stunted foliage, and increasing amount of shoots. | (No information.) |
| Se | Interveinal chlorosis or black spots at Se content at about 4 mg/L and complete bleaching or yellowing of younger leaves at higher Se content; pinkish spots on roots. | (No information.) |
| Zn | Chlorotic and necrotic leaf tips, interveinal chlorosis in new leaves, retarded growth of entire plant, injured roots resemble barbed wire. | Cereals and spinach. |

Perennial grasses benefit greatly by the addition of manure and sludges. Many are selected as vegetative filters because of their efficient interception and uptake of nutrients and generally longer active growing season. Others produce large quantities of biomass and thus can remove large amounts of nutrients, especially nitrogen, from the soil-plant system.

Bermudagrass pastures in the South have received annual rates of manure that supply over 400 pounds of nitrogen per acre without experiencing excessive nitrate levels in the forage. However, runoff and leaching potentials are high with these application rates, and they must be considered in the utilization plan.

Grass sods also accumulate nitrogen. An experiment in England carried out for 300 years at Rothamsted showed a steady increase in soil nitrogen for about 125 years before leveling off when an old plowed field was retired to grass (Wild 1988). However, where waste is spread on the soil surface, any ammonia nitrogen in the waste generally is lost to the air as a gas unless immediately incorporated.

Grass fields used for pasture or hay must have waste spread when the leaves of the plants are least likely to be contaminated with manure. If this is done, the grass quality is not lessened when harvested mechanically or grazed by animals (Simpson 1986).

Spreading wastes immediately after harvest and before regrowth is generally the best time for hay fields and pastures in a rotation system. This is especially important where composted sludge is applied on pasture at rates of more than 30 tons per acre. Cattle and sheep ingesting the compost inadvertently can undergo copper deficiency symptoms (USDA 1986).

Some reports show that manure applied to the soil surface has caused ammonium toxicity to growing crops (Klausner and Guest 1981). Young corn plants 8 inches high showed ammonia burn after topdressing with dairy manure during a period of warm, dry weather. The symptom disappeared after a few days with no apparent damage to the crop. This is very similar to corn burn affected during sidedressing by anhydrous ammonia. Liquid manure injected between corn rows is toxic to plant roots and causes temporary reduction in crop growth. Warming soil conditions dissipate the high ammonium levels, converting the ammonium to nitrates, and alleviate the temporary toxic conditions (Sawyer and Hoeft 1990).

**Table 6–4** Interaction among elements within plants and adjacent to plant roots

| **Major elements** | Antagonistic elements | Synergistic elements | **Trace elements** | Antagonistic elements | Synergistic elements |
|---|---|---|---|---|---|
| Ca | Al, B, Ba, Be, Cd, Co, Cr, Cs, Cu, F, Fe, Li, Mn, Ni, Pb, Sr, Zn | Cu, Mn, Zn | Cu | Cd, Al, Zn, Se, Mo, Fe, Ni, Mn | Ni, Mn, Cd |
| | | | Zn | Cd, Se, Mn, Fe, Ni, Cu | Ni, Cd |
| Mg | Al, Be, Ba, Cr, Mn, F, Zn, Ni, Co, Cu, Fe | Al, Zn | Cd | Zn, Cu, Al, Se, Mn, Fe, Ni | Cu, Zn, Pb, Mn, Fe, N |
| P | Al, As, B, Be, Cd, Cr, Cu, F, Fe, Hg, Mo, Mn, Ni, Pb, Rb, Se, Si, Sr, Zn | Al, B, Cu, F, Fe, Mn, Mo, Zn | B | Si, Mo, Fe | Mo, Fe |
| | | | Al | Cu, Cd | (No evidence.) |
| | | | Pb | --- | Cd |
| | | | Mn | Cu, Zn, Mo, Fe, Ar, Cr, Fe, Co, Cd, Al, Ni, Ar, Se | Cu, Cd, Al, Mo |
| K | Al, B, Hg, Cd, Cr, F, Mo, Mn, Rb | (No evidence.) | Fe | Zn, Cr, Mo, Mn, Co, Cu, Cd, B, Si | Cd, B |
| S | As, Ba, Fe, Mo, Pb, Se | F, Fe | | | |
| N | B, F, Cu | B, Cu, Fe, Mo | Mo | Cu, Mn, Fe, B | Mn, B. Si |
| Cl | Cr, I | (No evidence.) | Co | Mn, Fe | (No evidence.) |
| | | | Ni | Mn, Zn, Cu, Cd | Cu, Zn, Cd |

## (b) Horticultural crops

Vegetables and fruits benefit from applications of wastes; however, care must be taken because produce can be fouled or disease can be spread. Surface application of wastes to the soil around fruit trees will not cause either problem, but spray applications of liquid waste could.

Manure or sludge applied and plowed under before planting will not cause most vegetables to be unduly contaminated with disease organisms as long as they are washed and prepared according to good food industry standards. However, the scab disease may be promoted on the skin of potatoes with the addition of organic wastes. Well rotted or composted manure can be used to avoid excessive scabbing if it is plowed under before the potatoes are planted (Martin and Leonard 1949). Additional guidelines for the use of municipal sludge are in table 6–5.

**Table 6–5** Summary of joint EPA/FDA/USDA guidelines for sludge application for fruit and vegetable production (USEPA 1983)

| | |
|---|---|
| Annual and cumulative Cd rates: | Annual rate should not exceed 0.5 kg/ha (0.446 lb/ac). Cumulative Cd loadings should not exceed 5, 10, or 20 kg/ha, depending on CEC values of <5, 5 to 15, and >15 meq/100g, respectively, and soil pH. |
| Soil pH: | Soil pH (plow zone - top 6 inches) should be 6.5 or greater at time of each sludge application. |
| PCB's: | Sludges that have PCB concentrations of more than 10 ppm should be incorporated into the soil. |
| Pathogen reduction: | Sludge should be treated by pathogen reduction process before soil application. A waiting period of 12 to 18 months before a crop is grown may be required, depending on prior sludge processing and disinfection. |
| Use of high-quality sludge: | High-quality sludge should not contain more than 25 ppm Cd, 1,000 ppm Pb, and 10 ppm PCB (dry weight basis). |
| Cumulative lead (Pb) application rate: | Cumulative Pb loading should not exceed 800 kg/ha (714 lb/ac). |
| Pathogenic organisms: | A minimum requirement is that crops to be eaten raw should not be planted in sludge-amended fields within 12 to 18 months after the last sludge application. Further assurance of safe and wholesome food products can be achieved by increasing the time interval to 36 months. This is especially warranted in warm, humid climates. |
| Physical contamination and filth: | Sludge should be applied directly to soil and not directly to any human food crop. Crops grown for human consumption on sludge-amended fields should be processed using good food industry practices, especially for root crops and low-growing fresh fruits and vegetables. |
| Soil monitoring: | Soil monitoring should be performed on a regular basis, at least annually for pH. Every few years, soil tests should be run for Cd and Pb. |
| Choice of crop type: | Plants that do not accumulate heavy metals are recommended. |

## (c) Vegetated filter strips for agricultural waste treatment

Vegetated filter strips are designed strips or areas of vegetation growing downgradient of an animal production facility or cropland where animal waste has been applied. The strips can filter nutrients, sediment, organics, agrichemicals, and pathogens from runoff received from the contributing areas.

Four processes are involved in the removal of the elements in the run-on water. The first process is deposition of sediment (solid material) in the strip. A vegetated filter strip is composed of grasses or other dense vegetation that offers resistance to shallow overland flow. The decrease in flow velocity at the upslope edge of the vegetated filter strip greatly reduces the sediment transport capacity, and suspended solids are deposited.

In the second process the vegetation provides for surface run-on water to enter the soil profile. Once infiltrated into the soil, the elements are entrapped by the chemical, physical, and biological processes and are transformed into plant nutrients or organic components of the soil.

In the third process some soluble nutrients moving with the run-on water can be directly absorbed through the plant leaves and stems, and in the fourth, the thick, upright vegetation adheres solid particles that are being carried in the runoff, physically filtering them out.

In all of the processes, the nutrients taken from the run-on water by the plants transform a potential pollutant into vegetative biomass that can be used for forage, fiber, or mulch material.

Results from recent research show that vegetated filter strips have a wide range of effectiveness (Adam et al. 1986; Dillaha et at. 1988; Doyle et al. 1977; Schwer and Clausen 1989; Young et al. 1980). Variations in effectiveness are associated with individual site conditions, both the vegetated filter strip site and contributing area.

Land slope, soils, land use and management, climate, vegetation type and density, application rates for sites periodically loaded, and concentration and characteristics of constituents in incoming water are all important site characteristics that influence effectiveness. Operation and management of the contributing area, along with maintenance of the vegetated filter strip influence the ability of the total system to reduce the concentration and amount of contaminants contained in the runoff from the site. Knowledge of site variables is essential before making planning decisions about how well vegetated filter strips perform.

Research and operation sites exhibit certain characteristics that should be considered in planning a vegetated filter strip:

- Sheet flow must be maintained. Concentrated flow should be avoided unless low velocity grass waterways are used.
- Hydraulic loading must be carefully controlled to maintain desired depth of flow.
- Application of process generated wastewater must be periodically carried out to allow rest periods for the vegetated filter strip. Storage of wastewater is essential for rest periods and for climatic influences.
- Unless infiltration occurs, removal of soluble constituents from the run-on water will be minimal.
- Removal of suspended solids and attached constituents from the run-on can be high, in the range of 60 to 80 percent for properly installed and maintained strips.
- Vegetated filter strips should not be used as a substitute for other appropriate structural and management practices. They generally are not a stand-alone practice.
- Maintenance that includes proper care of the vegetation and removal of the accumulated solids must be performed.
- Proper siting is essential to assure uniform slopes can be installed and maintained along and perpendicular to the flow path.

The criteria for planning, design, implementation, and operation and maintenance of vegetated filter strips for livestock operations and manure application sites are in Conservation Practice Standard 393, "Filter Strip."

## (d) Forest land for agricultural waste treatment

Forest land provides an area for recycling agricultural waste. Wastewater effluent has been applied to some forest sites over extended periods of time with good nutrient removal efficiency and minimal impact on surface or ground water. On most sites the soil is covered with layers, some several inches thick, of organic material. This material can efficiently remove sediment and phosphorus from the effluent. Nitrogen in the form of nitrates is partly removed from the wastewater in the top few feet of the soil, and the added fertility contributes to increased tree and understory growth. Caution must be taken not to over apply water that will leach nitrates out of the root zone and down toward the ground water. Digested sludge also has been applied to forest.

Considerable amounts of nutrients are taken up by trees. Many of these nutrients are redeposited and recycled annually in the leaf litter. Leaves make up only 2 percent of the total dry weight of northern hardwoods. Harvesting trees with leaves on increases the removal of plant nutrients by the following percentages over that for trees without leaves:

| | |
|---|---|
| Calcium | = 12% |
| Potassium | = 15% |
| Phosphorus | = 4% |
| Nitrogen | = 19% |

Whole tree harvesting of hardwoods removes almost double the nutrients removed when only the stemwood is taken. Stemwood, the usual harvested bole or log taken from the tree for lumber, makes up about 80 percent of the aboveground biomass (Hornbeck and Kropelin 1982).

Riparian forest buffers are effective ecosystems between utilization areas and water bodies to control transport of contaminants from nonpoint sources (Lowrance et al. 1985). No specific literature has been reported on using these areas for utilization of nutrients in agricultural waste. These areas should be maintained to entrap nutrients in runoff and protect water bodies. They should not be used for waste spreading.

Only 10 percent of the nitrogen in a 45-year-old Douglas fir forest ecosystem is in the trees. The greater part of the nutrient sink in a coniferous forest is in the tree roots and soil organic matter. Although nitrogen uptake in forests exceeds 100 pounds per acre per year, less than 20 percent net is accumulated in eastern hardwood forest. The greater part of the assimilation is recycled from the soil and litter. Continued application rates of agricultural waste should be adjusted to meet the long-term sustainable need of the forest land, which generally is a half to two thirds that of the annual row crops (Keeney 1980).

## 651.0606 Nutrient removal by harvesting of crops

The nutrient content of a plant depends on the amount of nutrients available to the plant and on the environmental growing condition. The critical level of nutrient concentration of the dry harvested material of the plant leaf is about 2 percent nitrogen, 0.25 percent phosphorus, and 1 percent potassium. Where nutrients are available in the soil in excess of plant sufficiency levels, the percentages can more than double.

In forage crops, the percent composition for nitrogen can range from 1.2 to 2.8 percent, averaging around 2 percent of the dry harvested material of the plant. The concentrations can reach as high as 4.5 percent, however, if the soil system has high levels of nitrogen (Walsh and Beaton 1973).

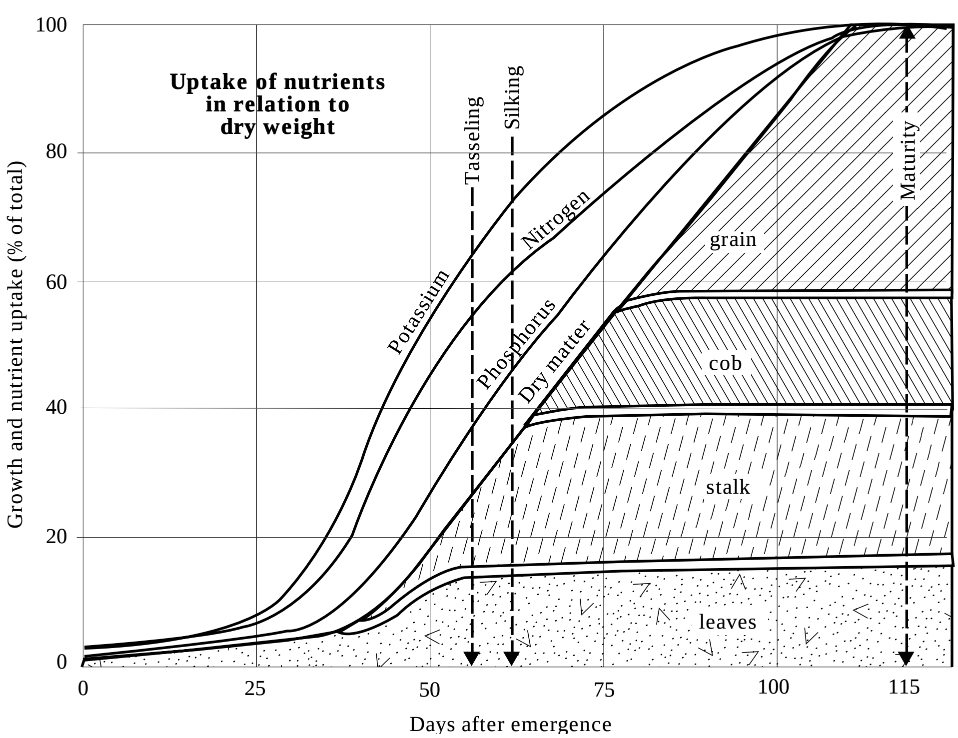
The total uptake of nutrients by crops from agricultural waste applications increases as the crop yields increase, and crop yields for the most part increase with increasing soil nutrients, provided toxic levels are not reached or nutrient imbalances do not occur. The total nutrient uptake continues to increase with yield, but the relation does not remain a constant linear relationship.

Two important factors that affect nutrient uptake and removal by crop harvest are the percent nutrient composition in the plant tissue and the crop biomass yield. In general, grasses contain their highest percentage of nutrients, particularly nitrogen, during the rapid growth stage of stem elongation and leaf growth.

Nitrogen uptake in grasses, like corn (fig. 6–5), follows an S-shaped uptake curve with very low uptake the first 30 days of growth, but rises sharply until flowering, then decreases with maturity.

Harvesting the forage before it flowers would capture the plant's highest percent nutrient concentration. Multiple cuttings during the growing season maximizes dry matter production. A system of two or three harvests per year at the time of grass heading would optimize the dry matter yield and plant tissue concentration, thus maximizing nutrient uptake and removal.

**Figure 6–5** Growth and nutrient uptake by corn (adapted from Hanaway 1962)



## (a) Nutrient uptake calculation

Table 6–6 can be used to calculate the approximate nutrient removal by agricultural crops. Typical crop yields are given only as default values and should be selected only in lieu of local information.

1. Select the crop or crops that are to be grown in the cropping sequence.
2. Determine the plant nutrient percentage of the crop to be harvested as a percentage of the dry or wet weight depending on the crop value given in table 6–6.
3. Determine the crop yield in pounds per acre. Weight to volume conversion are given.
4. Multiply the crop yield by the percentage of nutrient in the crop.

The solution is pounds per acre of nutrients removed in the harvested crop.

## (b) Nutrient uptake example

Corn and alfalfa are grown in rotation and harvested as grain and silage corn and alfalfa hay. Follow the above steps to calculate the nutrient taken up and removed in the harvested crop.

1. Crops to be grown: corn and alfalfa

2. Plant nutrient percentage in harvested crop (table 6–6):

   corn grain: 1.61% nitrogen
   0.28% phosphorus
   0.40% potassium

   corn silage: 1.10% nitrogen
   0.25% phosphorus
   1.09% potassium

   alfalfa: 2.25% nitrogen
   0.22% phosphorus
   1.87% potassium

3. Crop yield taken from local data base:

   corn grain: 130 bu/ac @ 56 lb/bu
   = 7,280 lb.

   corn silage: 22 tons/ac @ 2,000 lb/ton @ 35% dm
   = 15,400 lb

   alfalfa hay: 6 tons/ac @ 2,000 lb/ton
   = 12,000 lb

4. Multiplying percent nutrients contained in the crop harvested by the dry matter yield:

   corn grain:
   1.61% N x 7,280 lb = 117 lb N
   0.28% P x 7,280 lb = 20 lb P
   0.40% K x 7,280 lb = 29 lb K

   corn silage:
   1.10% N x 15,400 lb = 169 lb N
   0.25% P x 15,400 lb = 39 lb P
   1.09% K x 15,400 lb = 168 lb K

   alfalfa:
   2.25% N x 12,000 lb = 270 lb N
   0.22% P x 12,000 lb = 26 lb P
   1.87% K x 12,000 lb = 224 lb K

Nutrient values are given as elemental P and K. The conversion factors for phosphates and potash are:

$$\text{lb P x 2.3 = lb } P_2O_5$$
$$\text{lb K x 1.2 = lb } K_2O$$

Under alfalfa, nitrogen includes that fixed symbiotically from the air by alfalfa.

Table 6–6 shows the nutrient concentrations that are average values derived from plant tissue analysis values, which can have considerable range because of climatic conditions, varietal differences, soil conditions, and soil fertility status. Where available, statewide or local data should be used in lieu of the table values.

**Table 6–6** Plant nutrient uptake by specified crop and removed in the harvested part of the crop (Kilmer 1982; Morrison 1956; Sanchez 1976; USDA 1985)

| Crop | Dry wt. lb/bu | Typical yield/acre plant part | Average concentration of nutrients (%) N | P | K | Ca | Mg | S | Cu | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Grain crops** | | | % of the dry harvested material | | | | | | | | |
| Barley | 48 | 50 bu | 1.82 | 0.34 | 0.43 | 0.05 | 0.10 | 0.16 | 0.0016 | 0.0016 | 0.0031 |
| | | 1 T. straw | 0.75 | 0.11 | 1.25 | 0.40 | 0.10 | 0.20 | 0.0005 | 0.0160 | 0.0025 |
| Buckwheat | 48 | 30 bu | 1.65 | 0.31 | 0.45 | 0.09 | | | 0.0009 | 0.0034 | |
| | | 0.5 T. straw | 0.78 | 0.05 | 2.26 | 1.40 | | 0.01 | | | |
| Corn | 56 | 120 bu | 1.61 | 0.28 | 0.40 | 0.02 | 0.10 | 0.12 | 0.0007 | 0.0011 | 0.0018 |
| | | 4.5 T. stover | 1.11 | 0.20 | 1.34 | 0.29 | 0.22 | 0.16 | 0.0005 | 0.0166 | 0.0033 |
| Oats | 32 | 80 bu | 1.95 | 0.34 | 0.49 | 0.08 | 0.12 | 0.20 | 0.0012 | 0.0047 | 0.0020 |
| | | 2 T. straw | 0.63 | 0.16 | 1.66 | 0.20 | 0.20 | 0.23 | 0.0008 | 0.0030 | 0.0072 |
| Rice | 45 | 5,500 lb | 1.39 | 0.24 | 0.23 | 0.08 | 0.11 | 0.08 | 0.0030 | 0.0022 | 0.0019 |
| | | 2.5 T. straw | 0.60 | 0.09 | 1.16 | 0.18 | 0.10 | | | 0.0316 | |
| Rye | 56 | 30 bu | 2.08 | 0.26 | 0.49 | 0.12 | 0.18 | 0.42 | 0.0012 | 0.0131 | 0.0018 |
| | | 1.5 T. straw | 0.50 | 0.12 | 0.69 | 0.27 | 0.07 | 0.10 | 0.0300 | 0.0047 | 0.0023 |
| Sorghum | 56 | 60 bu | 1.67 | 0.36 | 0.42 | 0.13 | 0.17 | 0.17 | 0.0003 | 0.0013 | 0.0013 |
| | | 3 T. stover | 1.08 | 0.15 | 1.31 | 0.48 | 0.30 | 0.13 | | 0.0116 | |
| Wheat | 60 | 40 bu | 2.08 | 0.62 | 0.52 | 0.04 | 0.25 | 0.13 | 0.0013 | 0.0038 | 0.0058 |
| | | 1.5 T. straw | 0.67 | 0.07 | 0.97 | 0.20 | 0.10 | 0.17 | 0.0003 | 0.0053 | 0.0017 |
| **Oil crops** | | | % of the dry harvested material | | | | | | | | |
| Flax | 56 | 15 bu | 4.09 | 0.55 | 0.84 | 0.23 | 0.43 | 0.25 | | 0.0061 | |
| | | 1.75 T. straw | 1.24 | 0.11 | 1.75 | 0.72 | 0.31 | 0.27 | | | |
| Oil palm | | 22,000 lb | 1.13 | 0.26 | 0.16 | 0.19 | 0.09 | | 0.0043 | 0.0225 | |
| | | 5 T. fronds & stems | 1.07 | 0.49 | 1.69 | | 0.36 | | | | |
| Peanuts | 22-30 | 2,800 lb | 3.60 | 0.17 | 0.50 | 0.04 | 0.12 | 0.24 | 0.0008 | 0.0040 | |
| | | 2.2 T. vines | 2.33 | 0.24 | 1.75 | 1.00 | 0.38 | 0.36 | | 0.0051 | |
| Rapeseed | 50 | 35 bu | 3.60 | 0.79 | 0.76 | | 0.66 | | | | |
| | | 3 T. straw | 4.48 | 0.43 | 3.37 | 1.47 | 0.06 | 0.68 | 0.0001 | 0.0008 | |
| Soybeans | 60 | 35 bu | 6.25 | 0.64 | 1.90 | 0.29 | 0.29 | 0.17 | 0.0017 | 0.0021 | 0.0017 |
| | | 2 T. stover | 2.25 | 0.22 | 1.04 | 1.00 | 0.45 | 0.25 | 0.0010 | 0.0115 | 0.0038 |
| Sunflower | 25 | 1,100 lb | 3.57 | 1.71 | 1.11 | 0.18 | 0.34 | 0.17 | | 0.0022 | |
| | | 4 T. stover | 1.50 | 0.18 | 2.92 | 1.73 | 0.09 | 0.04 | | 0.0241 | |

**Table 6–6** Plant nutrient uptake by specified crop and removed in the harvested part of the crop — Continued

| Crop | Dry wt. lb/bu | Typical yield/acre plant part | N | P | K | Ca | Mg | S | Cu | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Average concentration of nutrients (%) | | | | | | | | |
| **Fiber crops** | | % of the dry harvested material | | | | | | | | | |
| Cotton | | 600 lb. lint & | | | | | | | | | |
| | | 1,000 lb seeds | 2.67 | 0.58 | 0.83 | 0.13 | 0.27 | 0.20 | 0.0040 | 0.0073 | 0.0213 |
| | | burs & stalks | 1.75 | 0.22 | 1.45 | 1.40 | 0.40 | 0.75 | | | |
| Pulpwood | | 98 cords | 0.12 | 0.02 | 0.06 | | 0.02 | | | | |
| | | bark, branches | 0.12 | 0.02 | 0.06 | | 0.02 | | | | |
| **Forage crops** | | % of the dry harvested material | | | | | | | | | |
| Alfalfa | | 4 tons | 2.25 | 0.22 | 1.87 | 1.40 | 0.26 | 0.24 | 0.0008 | 0.0055 | 0.0053 |
| Bahiagrass | | 3 tons | 1.27 | 0.13 | 1.73 | 0.43 | 0.25 | 0.19 | | | |
| Big bluestem | | 3 tons | 0.99 | 0.85 | 1.75 | | 0.20 | | | | |
| Birdsfoot trefoil | | 3 tons | 2.49 | 0.22 | 1.82 | 1.75 | 0.40 | | | | |
| Bluegrass-pastd. | | 2 tons | 2.91 | 0.43 | 1.95 | 0.53 | 0.23 | 0.66 | 0.0014 | 0.0075 | 0.0020 |
| Bromegrass | | 5 tons | 1.87 | 0.21 | 2.55 | 0.47 | 0.19 | 0.19 | 0.0008 | 0.0052 | |
| Clover-grass | | 6 tons | 1.52 | 0.27 | 1.69 | 0.92 | 0.28 | 0.15 | 0.0008 | 0.0106 | |
| Dallisgrass | | 3 tons | 1.92 | 0.20 | 1.72 | 0.56 | 0.40 | | | | |
| Guineagrass | | 10 tons | 1.25 | 0.44 | 1.89 | | 0.43 | 0.20 | | | |
| Bermudagrass | | 8 tons | 1.88 | 0.19 | 1.40 | 0.37 | 0.15 | 0.22 | 0.0013 | | |
| Indiangrass | | 3 tons | 1.00 | 0.85 | 1.20 | 0.15 | | | | | |
| Lespedeza | | 3 tons | 2.33 | 0.21 | 1.06 | 1.12 | 0.21 | 0.33 | | 0.0152 | |
| Little bluestem | | 3 tons | 1.10 | 0.85 | 1.45 | | 0.20 | | | | |
| Orchardgrass | | 6 tons | 1.47 | 0.20 | 2.16 | 0.30 | 0.24 | 0.26 | 0.0017 | 0.0078 | |
| Pangolagrass | | 10 tons | 1.30 | 0.47 | 1.87 | | 0.29 | 0.20 | | | |
| Paragrass | | 10.5 tons | 0.82 | 0.39 | 1.59 | 0.39 | 0.33 | 0.17 | | | |
| Red clover | | 2.5 tons | 2.00 | 0.22 | 1.66 | 1.38 | 0.34 | 0.14 | 0.0008 | 0.0108 | 0.0072 |
| Reed canarygrass | | 6.5 tons | 1.35 | 0.18 | | 0.36 | | | | | |
| Ryegrass | | 5 tons | 1.67 | 0.27 | 1.42 | 0.65 | 0.35 | | | | |
| Switchgrass | | 3 tons | 1.15 | 0.10 | 1.90 | 0.28 | 0.25 | | | | |
| Tall fescue | | 3.5 tons | 1.97 | 0.20 | 2.00 | 0.30 | 0.19 | | | | |
| Timothy | | 2.5 tons | 1.20 | 0.22 | 1.58 | 0.36 | 0.12 | 0.10 | 0.0006 | 0.0062 | 0.0040 |
| Wheatgrass | | 1 ton | 1.42 | 0.27 | 2.68 | 0.36 | 0.24 | 0.11 | | | |
| **Forest** | | % of the dry harvested material | | | | | | | | | |
| Leaves | | | 0.75 | 0.06 | 0.46 | | | | | | |
| Northern hardwoods | | 50 tons | 0.20 | 0.02 | 0.10 | 0.29 | | | | | |
| Douglas fir | | 76 tons | 0.16 | | | | | | | | |

**Table 6–6** Plant nutrient uptake by specified crop and removed in the harvested part of the crop — Continued

| Crop | Dry wt. lb/bu | Typical yield/acre plant part | Average concentration of nutrients (%) N | P | K | Ca | Mg | S | Cu | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fruit crops** | | % of the fresh harvested material | | | | | | | | | |
| Apples | | 12 tons | 0.13 | 0.02 | 0.16 | 0.03 | 0.02 | 0.04 | 0.0001 | 0.0001 | 0.0001 |
| Bananas | | 9,900 lb. | 0.19 | 0.02 | 0.54 | 0.23 | 0.30 | | | | |
| Cantaloupe | | 17,500 lb. | 0.22 | 0.09 | 0.46 | | 0.34 | | | | |
| Coconuts | | 0.5 tons–dry copra | 5.00 | 0.60 | 3.33 | 0.21 | 0.36 | 0.34 | 0.0010 | | 0.0076 |
| Grapes | | 12 tons | 0.28 | 0.10 | 0.50 | | 0.04 | | | | |
| Oranges | | 54,000 lb. | 0.20 | 0.02 | 0.21 | 0.06 | 0.02 | 0.02 | 0.0004 | 0.0001 | 0.0040 |
| Peaches | | 15 tons | 0.12 | 0.03 | 0.19 | 0.01 | 0.03 | 0.01 | | | 0.0010 |
| Pineapple | | 17 tons | 0.43 | 0.35 | 1.68 | 0.02 | 0.18 | 0.04 | | | |
| Tomatoes | | 22 tons | 0.30 | 0.04 | 0.33 | 0.02 | 0.03 | 0.04 | 0.0002 | 0.0003 | 0.0001 |
| **Silage crops** | | % of the dry harvested material | | | | | | | | | |
| Alfalfa haylage (50% dm) | | 10 wet/5 dry | 2.79 | 0.33 | 2.32 | 0.97 | 0.33 | 0.36 | 0.0009 | 0.0052 | |
| Corn silage (35% dm) | | 20 wet/7 dry | 1.10 | 0.25 | 1.09 | 0.36 | 0.18 | 0.15 | 0.0005 | 0.0070 | |
| Forage sorghum (30% dm) | | 20 wet/6 dry | 1.44 | 0.19 | 1.02 | 0.37 | 0.31 | 0.11 | 0.0032 | 0.0045 | |
| Oat haylage (40% dm) | | 10 wet/4 dry | 1.60 | 0.28 | 0.94 | 0.31 | 0.24 | 0.18 | | | |
| Sorghum-sudan (50% dm) | | 10 wet/5 dry | 1.36 | 0.16 | 1.45 | 0.43 | 0.34 | 0.04 | | 0.0091 | |
| **Sugar crops** | | % of the fresh harvested material | | | | | | | | | |
| Sugarcane | | 37 tons | 0.16 | 0.04 | 0.37 | 0.05 | 0.04 | 0.04 | | | |
| Sugar beets | | 20 tons | 0.20 | 0.03 | 0.14 | 0.11 | 0.08 | 0.03 | 0.0001 | 0.0025 | |
| tops | | | 0.43 | 0.04 | 1.03 | 0.18 | 0.19 | 0.10 | 0.0002 | 0.0010 | |
| **Tobacco** | | % of the dry harvested material | | | | | | | | | |
| All types | | 2,100 lb. | 3.75 | 0.33 | 4.98 | 3.75 | 0.90 | 0.70 | 0.0015 | 0.0275 | 0.0035 |
| **Turf grass** | | % of the dry harvested material | | | | | | | | | |
| Bluegrass | | 2 tons | 2.91 | 0.43 | 1.95 | 0.53 | 0.23 | 0.66 | 0.0014 | 0.0075 | 0.0020 |
| Bentgrass | | 2.5 tons | 3.10 | 0.41 | 2.21 | 0.65 | 0.27 | 0.21 | | | |
| Bermudagrass | | 4 tons | 1.88 | 0.19 | 1.40 | 0.37 | 0.15 | 0.22 | 0.0013 | | |

**Table 6–6** Plant nutrient uptake by specified crop and removed in the harvested part of the crop — Continued

| Crop | Dry wt. lb/bu | Typical yield/acre plant part | Average concentration of nutrients (%) N | P | K | Ca | Mg | S | Cu | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Vegetable crops** | | | % of the fresh harvested material | | | | | | | | |
| Bell peppers | | 9 tons | 0.40 | 0.12 | 0.49 | | 0.04 | | | | |
| Beans, dry | | 0.5 ton | 3.13 | 0.45 | 0.86 | 0.08 | 0.08 | 0.21 | 0.0008 | 0.0013 | 0.0025 |
| Cabbage | | 20 tons | 0.33 | 0.04 | 0.27 | 0.05 | 0.02 | 0.11 | 0.0001 | 0.0003 | 0.0002 |
| Carrots | | 13 tons | 0.19 | 0.04 | 0.25 | 0.05 | 0.02 | 0.02 | 0.0001 | 0.0004 | |
| Cassava | | 7 tons | 0.40 | 0.13 | 0.63 | 0.26 | 0.13 | | | | |
| Celery | | 27 tons | 0.17 | 0.09 | 0.45 | | | | | | |
| Cucumbers | | 10 tons | 0.20 | 0.07 | 0.33 | | 0.02 | | | | |
| Lettuce (heads) | | 14 tons | 0.23 | 0.08 | 0.46 | | | | | | |
| Onions | | 18 tons | 0.30 | 0.06 | 0.22 | 0.07 | 0.01 | 0.12 | 0.0002 | 0.0050 | 0.0021 |
| Peas | | 1.5 tons | 3.68 | 0.40 | 0.90 | 0.08 | 0.24 | 0.24 | | | |
| Potatoes | | 14.5 tons | 0.33 | 0.06 | 0.52 | 0.01 | 0.03 | 0.03 | 0.0002 | 0.0004 | 0.0002 |
| Snap beans | | 3 tons | 0.88 | 0.26 | 0.96 | 0.05 | 0.10 | 0.11 | 0.0005 | 0.0009 | |
| Sweet corn | | 5.5 tons | 0.89 | 0.24 | 0.58 | | 0.07 | 0.06 | | | |
| Sweet potatoes | | 7 tons | 0.30 | 0.04 | 0.42 | 0.03 | 0.06 | 0.04 | 0.0002 | 0.0004 | 0.0002 |
| Table beets | | 15 tons | 0.26 | 0.04 | 0.28 | 0.03 | 0.02 | 0.02 | 0.0001 | 0.0007 | |
| **Wetland plants** | | | % of the dry harvested material | | | | | | | | |
| Cattails | | 8 tons | 1.02 | 0.18 | | | | | | | |
| Rushes | | 1 ton | 1.67 | | | | | | | | |
| Saltgrass | | 1 ton | 1.44 | 0.27 | 0.62 | | | | | | |
| Sedges | | 0.8 ton | 1.79 | 0.26 | | 0.66 | | | | | |
| Water hyacinth | | | | 3.65 | 0.87 | 3.12 | | | | | |
| Duckweed | | | 3.36 | 1.00 | 2.13 | | | | | | |
| Arrowweed | | | 2.74 | | | | | | | | |
| Phragmites | | | 1.83 | 0.10 | 0.52 | | | | | | |

# 651.0607 References

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